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MODULAR DIGITAL RADIO FREQUENCY (RF) RECEIVER SYSTEM (MODRFS) PROGRAM

System Architecture Definition Report

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This report documents the top-level MODRFS architecture. The architecture study began by identifying those particular missions, weapons systems, and sensor systems consistent with current and emerging Northrop Grumman ESSS products. Receiver functional and performance requirements for each of these applications were compiled in a common tabular format. From these, a baseline set of performance objectives was chosen to span the widest set of applications and modes. A baseline modular receiver architecture was generated to meet these common requirements. The functionality and interface descriptions for the resulting modular building objects (MBOs) are provided in this report.

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List of Acronyms

Acronym	Meaning
A/D	Analog to Digital Converter
ADC	Analog to Digital Converter
AGC	Automatic Gain Control
AIU	Aperture Interface Unit
ASIC	Application Specific Integrated Circuit
BIT	Built-In Test
BPF	Bandpass Filter
BW	Bandwidth
CDL	Common Data Link
COTS	Commercial Off-the-Shelf
CPU	Central Processing Unit
DAC	Digital to Analog Converter
DC	Direct Current
DF	Direction Finding
DIQ	Digital I/Q
ECCM	Electronic Counter Counter Measures
ECL	Emitter Compelled Logic
ENOB	Effective Number of Bits
EPROM	Electrically Programmable Read Only Memory
ESM	Electronic Support Measures
EW	Electronic Warfare
FFT	Fast Fourier Transform
FIFO	First In First Out
FIR	Finite Impulse Response
FM	Frequency Modulation
FPGA	Field Programmable Gate Array
GBS	Global Broadcast System
GMTI	Ground Moving Target Indicator
HARM	Homing Anti-Radiation Missile
ISS	Integrated Sensor Systems
I/O	Input / Output
I/Q	In phase / Quadrature
IF	Intermediate Frequency
IFFT	Inverse Fast Fourier Transform
JTIDS	Joint Tactical Information Distribution System
LNA	Low Noise Amplifier
LO	Local Oscillator
LPRF	Low-Power RF
LRM	Line Replaceable Module

List of Acronyms (continued)

Acronym	Meaning
MB	Medium Bandwidth
MBO	Modular Building Object
MCM	Multi-Chip Module
MCU	Module Control Unit
MMIC	Monolithic Microwave Integrated Circuit
MODRFS	Modular Digital RF Receiver System
NAGC	Noise Automatic Gain Control
NB	Narrow Bandwidth
NCO	Numerically Controlled Oscillator
OSA	Open Systems Architecture
PDW	Pulse Descriptor Word
PE	Parameter Encoder
PIN	P-Intrinsic-N
RF	Radio Frequency
R/P	Receiver Protector
SAR	Synthetic Aperture Radar
SEAD	Suppression of Enemy Air Defenses
SEI	Specific Emitter Identification
SIGINT	Signals Intelligence
STAP	Space Time Adaptive Processing
T/R	Transmit / Receive
TCDL	Tactical Common Data Link
TOIP	Third Order Intercept Point
TTL	Transistor-Transistor Logic
UAV	Unmanned Aerial Vehicle
VME	Versa Module Eurocard
VSWR	Voltage-Wave Standing Ratio
WB	Wide Bandwidth

1 Introduction

The Modular Digital RF Receiver System (MODRFS) program is a cooperative agreement program between the Air Force Research Laboratory (AFRL) and Northrop Grumman Electronic Sensors and Systems Sector (ESSS). The objectives of the program are to develop and demonstrate a modular receiver architecture and set of modular building objects for implementing receivers for radar, ESM, and communications applications.

The requirements for MODRFS are derived primarily from current and evolving radar applications. Most of these applications require bandwidth and dynamic range commensurate with near-term digital technology. Key elements of this receiver are an advanced analog-to-digital converter under development by TRW, and an innovative preprocessor being developed by Northrop Grumman. They will allow MODRFS to trade bandwidth for dynamic range so that, for example, a single receiver architecture can provide narrow-band, high-dynamic-range search for airborne targets as well as wide-band, moderate dynamic range for surface mapping. The wide band mode also allows MODRFS to provide ESM and communications functionality.

This report documents the top-level MODRFS architecture. As shown in Figure 1-1, the architecture study began by identifying those particular missions, weapons systems and sensor systems consistent with current and emerging Northrop Grumman ESSS products. Receiver functional and performance requirements for each of these applications were compiled in a common tabular format. From these, a baseline set of performance objectives was chosen to span the widest set of applications and modes. A baseline modular receiver architecture was generated to meet these common requirements. The functionality and interface descriptions for the resulting modular building objects (MBO's) are provided in this report.

Results of the MODRFS Architecture Study have shown the feasibility of implementing a multi-mode receiver consisting of six basic modular building objects:

1. RF channelizer,
2. RF down-converter,
3. IF down-converter,
4. Analog-to-digital converter,

5. Digital preprocessor, and
6. Module controller.

Variants of each of these modules allow the MODRFS architecture to be adapted to a wide range of specific radar, ESM and communications applications.

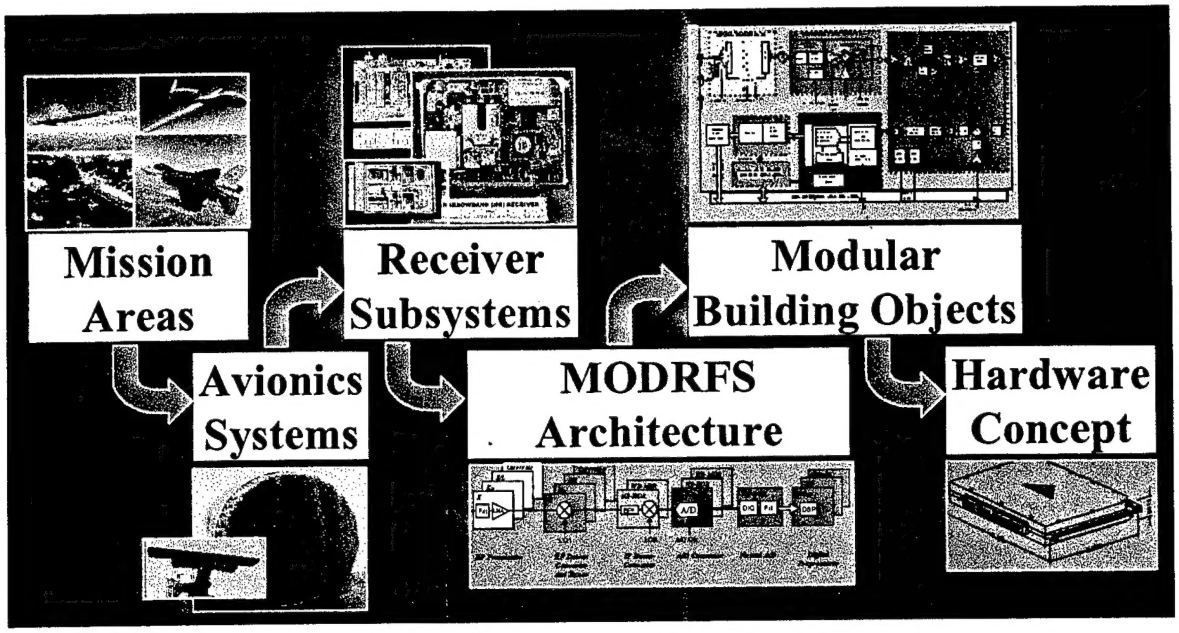

Figure 1-1. Graphical illustration of the methodology followed in the MODRFS Architecture Study.

1.1 Radar System Architecture Overview

MODRFS is being developed as a technology base to a family of receivers appropriate for a variety of applications, among which radar is of key importance. Open System Architecture (OSA) attributes will enable a maximum number of applications and will facilitate system upgrades. MODRFS will benefit from concurrent efforts at Northrop Grumman to develop highly modular systems, as well as efforts across government and industry to apply OSA standards.

RF sensor systems including radar require common essential elements: aperture, RF electronics, processing and platform and operator interfaces. A high-level depiction of the elements of a modern radar system is given in Figure 1-2.

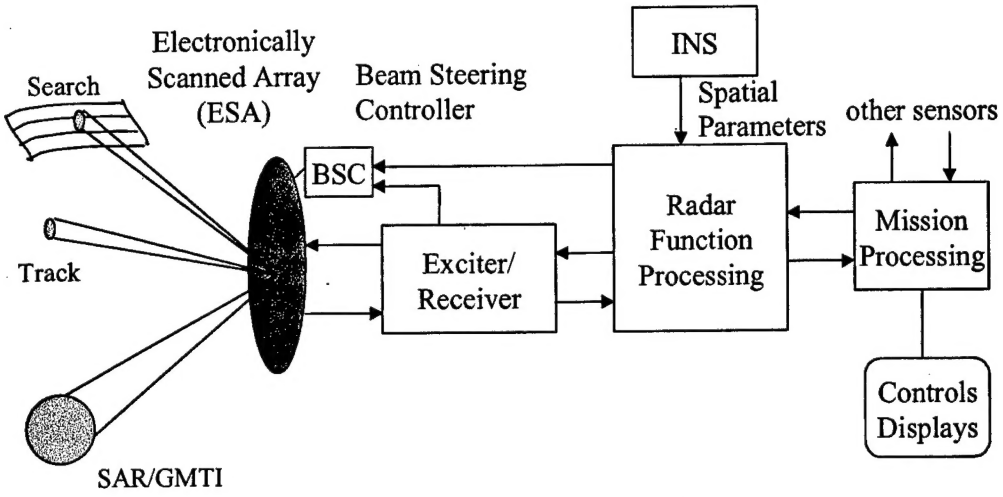

Figure 1-2 Elements of a typical radar system

The emergence of active apertures for many applications means that the final electronic stages of the transmit thread and the first electronic stages of the receive thread are incorporated within the aperture domain. Since radar measurements rely on referencing received waveforms to those transmitted, precise time synchronization and control are needed, requiring that high stability signals be generated. The equipment performing these operations is called the receiver/exciter (R/E) resources. This equipment performs "signal conditioning operations" between the aperture and the processor. Once dominated by primarily analog circuitry, digitization of received signals and digital generation of waveforms continue to revolutionize modern radar.

Digital processing is used to extract information about the target from the returned signal. The processor also directs the management and interleaving of the various radar modes and operations.

1.1.1 Receiver/Exciter Elements

Figure 1-3 is a block diagram expanding the receiver and exciter functional elements, including key RF, bus and discrete interfaces. The reference generator provides the common source of coherency used throughout the analog portion of the radar. The controller configures all the module parameters and performs low latency control operations such as managing automatic gain control (AGC) and alert/confirm mode operations. The synchronizer distributes timing information for all operations that must be precisely aligned in time.

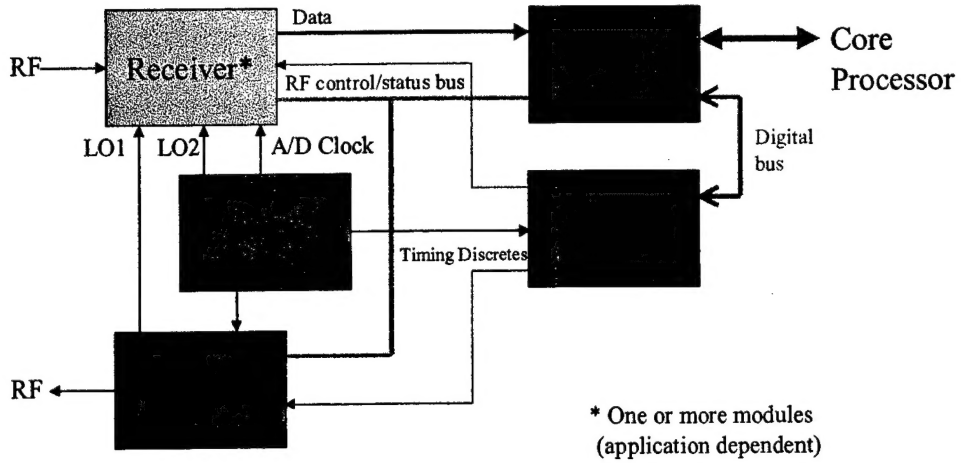

Figure 1-3 Key Low Power RF Modules and Interfaces Define a Highly Modular Realization

1.1.2 Radar receiver requirement flow-down

The flow-down of receive requirements is highly dependent upon the functions and level of performance needed for the particular application. Figure 1-4 illustrates the relationship between modular building object (MBO's) requirements to the system requirement flow-down process. The MODRFS objective is to address many RF system insertions with common MBO's. By identifying the requirements of many insertions, MODRFS is being designed to effectively fulfill them with an optimal family of common building blocks.

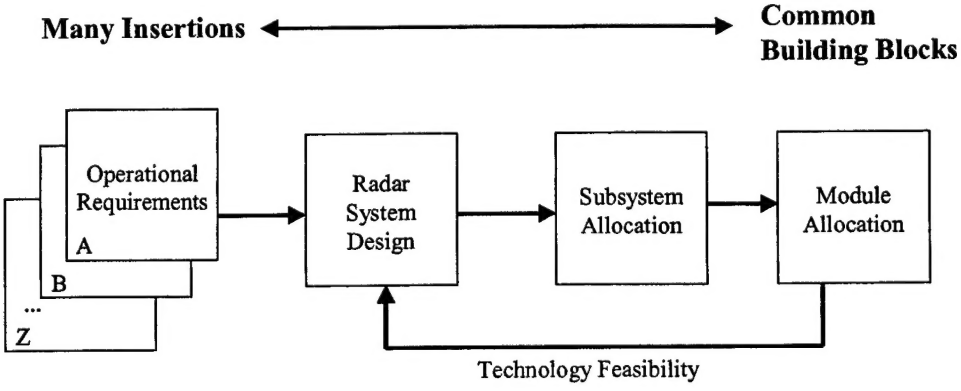

Figure 1-4 Stressing Requirements From Many System Applications Have Been Analyzed along with State-Of-The-Art Technology Capabilities to Develop an Optimal MODRFS Realization

The identification of key receiver parameters and their radar system impact is summarized in Table 1-1.

Table 1-1 Key Receiver Parameters and Radar System Impact

Receiver Parameter	Radar System Impact
RF Frequency Coverage	Antenna size, beamwidth and gain Atmospheric loss Degree of LPI
Noise Figure	Target detectability
Intercept Point (or IMD)	Target detectability amidst clutter and interference
Instantaneous Bandwidth	Corresponds to transmit waveform capabilities Range cell size
Dynamic Range	Extent over which signals can be accurately encoded in amplitude Target detectability amidst clutter and interference
Phase Noise	Extent over which signals can be accurately encoded in Doppler Target detectability amidst clutter and interference
Image Rejection	Ability to reject undesired signals that are by-products of frequency conversions
Channel Matching	Ability of receivers to be employed in adaptive cancellation of interferers
RF Channelization	Ability to minimize interference from adjacent signals Ability to accurately receive wideband waveforms
Instantaneous Bandwidth Selection	Ability to adjust bandwidth to optimally receive diverse waveforms
Output Data Rate	Ability to output necessary extracted information to processor

A discussion of pertinent missions and weapon systems and their sensor system requirements are provided in Section 2, which includes a summary of the specific receiver requirements that are the objective of the MODRFS program. Section 3 will address the baseline MODRFS architecture and describe the functionality and interfaces of each MBO.

2 Requirement Flow-Down from Missions and Applications

To categorize the wide range of military missions and weapon systems we have divided them into the seven mission areas depicted in Figure 2-1. Six of these consist of sensing and responding to airborne threats, surface threats, and undersea threats. The seventh mission area consists of the information, communication, and navigation services which tie the other six into a cohesive fighting force.

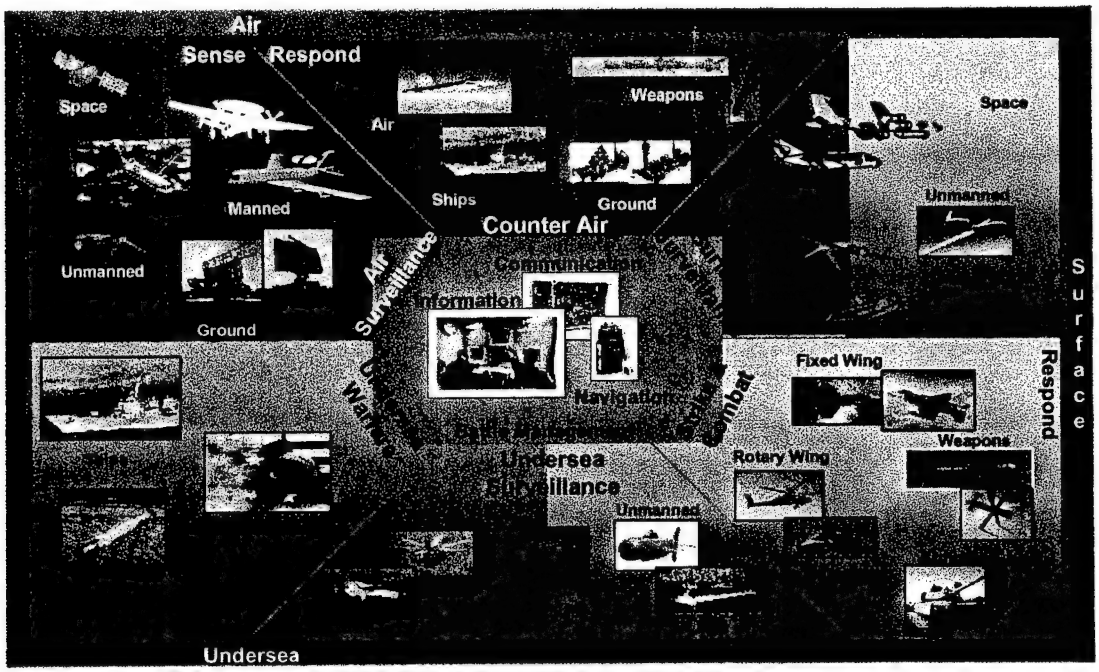

Figure 2-1. The Seven Mission Areas in which Northrop Grumman ESSS categorizes its products

The MODRFS architecture study task addressed RF sensor systems in five of the seven mission areas: air surveillance, counter air, surface surveillance, strike and combat, and battle management. The two undersea mission areas (undersea surveillance and undersea warfare) were excluded because they do not employ RF emissions as the primary mode of detection.

In the five primary mission areas, the MODRFS architecture study considered the sensor requirements for 23 different radar, ESM, and communications applications. Discussion of the receiver requirements for each of these 23 applications can be found in subsequent sections of this report.

2.1 Requirement Capture Methodology

To support capturing and comparing the requirements of so many different receiver applications, a generic, top-level receiver and description companion requirements table were developed, as shown in Figure 2-2. This receiver description is at a sufficiently high level to allow application to many diverse applications, such as air-to-air radar, air-to-surface radar, ESM, and wide band communications.

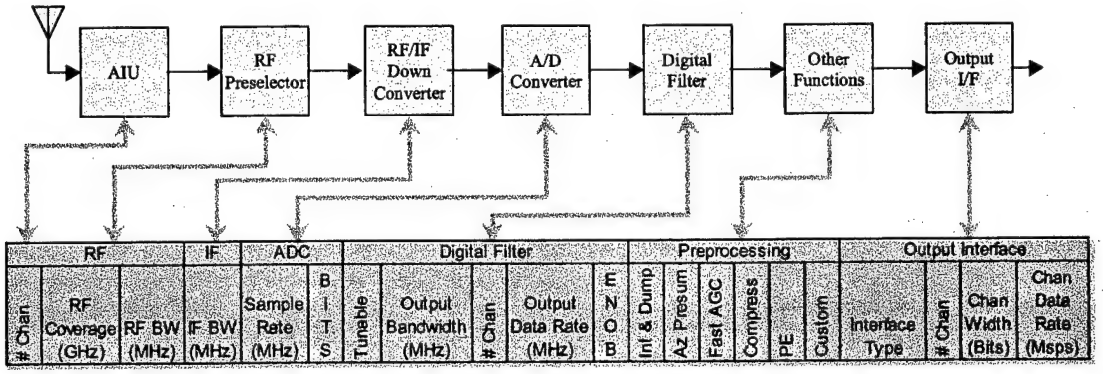

Figure 2-2. Generic receiver architecture and requirements table. The methodology followed to develop the MODRFS system architecture was to use this diagram and associated table to survey the requirements for different radar, ESM and communications systems. The data gathered allowed us to choose the most desirable common receiver parameters for MODRFS.

The aperture interface unit (AIU) provides the interface between the antenna and receiver electronics. It typically contains a low-noise amplifier to set the system noise figure, and may be implemented as part of a T/R module. The AIU is not part of MODRFS. The key parameter of concern to MODRFS is the number of simultaneous RF channels, since this will drive the number of receivers, and the number of receivers is useful for gaining a sense of the *scale* of the electronics required for the application.

The RF preselector controls the total tunable bandwidth of the receiver as well as the instantaneous RF bandwidth. In many applications, an RF channelizer is required to allow very broadband RF coverage with narrow enough RF channels to reduce interference. Of interest here was the total RF coverage (tunable) and instantaneous (single pulse) RF bandwidth.

The RF/IF down-converters translate the selected RF band to an intermediate frequency (IF). The IF down-converter performs a secondary translation for sampling by the A/D

converter. The down-conversion is typically accomplished in one to three stages. For IF-sampled systems, the final analog IF is typically centered at ¼ or ¾ of the sample rate of the A/D converter. For base-band (or I/Q) sampled systems, the final IF is positioned at zero frequency using an analog quadrature mixer in the last stage of down-conversion. Two A/D converters are used to sample the quadrature outputs at sample rates greater than the base bandwidth. Key parameter taken into consideration was the final analog IF bandwidth being sampled.

The A/D converter samples the analog IF signal and outputs a digital representation with a fixed number of bits. For IF-sampled systems, the A/D converter will sample at rates greater than twice the IF bandwidth. For base-band systems, two A/D converters sample at rates greater than the base-bandwidth. Some amount of oversampling is desired in either case to allow for realizable filters. Typically, the minimum oversampling is 4/3 times the minimum rates quoted above, although much higher ratios of oversampling are used in some cases. Key parameters of the A/D converter are the sample rate and the effective number of bits (ENOB). The ENOB is less than the number of resolution bits (BITS) at the A/D converter output. ENOB is obtained by measuring the total usable dynamic range (in dB) of the A/D converter with a sine-wave input accounting for both noise and spurious, and then converting that measured dynamic range into an equivalent number of bits using the formula ENOB = (Dynamic Range – 1.76 dB) / 6.02.

***The Preprocessor*:** In legacy applications, the output of the A/D converter went directly to the sensor signal processor. The A/D converter was essentially the output of the receiver – everything after that was signal/data processing. As such, the signal bandwidth, A/D data rate, and number of bits were all that was required to quantify the output of the receiver. However, technology advances have allowed the A/D converter to move forward in the system and to sample very wide band signals with high data rates. In some cases, the full bandwidth of the A/D converter is not desired, so it becomes necessary to apply digital filters after the A/D converter. In addition, the desired IF band may be positioned at frequencies offset from the final IF frequency to avoid spurs and harmonics generated in the analog electronics. In this case it is necessary to apply a final tuning function, which is done digitally. In essence, then, the final IF conversion stage of the receiver, once realized using analog technology, is now performed digitally.

Some key parameters for the preprocessor are: the input data, the effective number of bits required (accounting for the growth in dynamic range due to a decrease in noise bandwidth), whether a digital tuning function is required, and the number of digital channels. This final parameter accounts for those applications requiring a bank of digital filters (digital channelizer) rather than a single digital filter.

If digital interface and signal processing technology were fast enough, it would be possible to send the output of the digital filter (or even the A/D converter output) to the signal processors to perform all remaining signal processing functions. However, because of the high data rates, it is often more economical to perform some signal processing functions in hardware, and to send narrower bandwidth results to the signal processors. These preprocessing functions vary widely among applications, but several of the most common functions include: integrate and dump (for implementing single-pulse matched filters), azimuth pre-summing (used in SAR applications for integrating each range gate across azimuth over many pulses in a coherent integration period), fast automatic gain control (AGC), pulse compression (used in GMTI and mapping modes for compressing linear FM and phase-coded waveforms), parameter encoding (used in ESM modes for measuring pulse arrival time, amplitude, frequency, and pulse width), and other custom functions which may be tailored to each specific application.

The output interface function converts the final preprocessed data into a format and data rate commensurate with the digital interface to the signal processor. In many cases, the output interface communicates with commercial back-planes or bus standards such as VME, G-Link, FibreChannel, or even Ethernet. Depending on the data rates involved, several such interface channels may be required to move the high bandwidth samples into the signal processor. Key parameters relating to the output interface include: type of interface, channel data width (1 bit for serial, or typically 16-32 for parallel), channel data rate, and number of channels required.

Requirement Collection: Requirements for specific radar, ESM and communication systems were gathered for each of the blocks described above (see Figure 2-2) during meetings with key system engineers throughout Northrop Grumman ESSS. Receiver parameter tables, using the bottom part of Figure 2-2 as the column headings, were created for

a total of 23 systems divided into the following system application categories, which follow the mission areas described in Figure 2-1:

1. Surface Surveillance Radar
2. Air Surveillance Radar
3. Strike, Combat and Counter Air Radar
4. Electronic Warfare
5. Communications

An example of the table format is shown in Table 2-1. These tables were used to capture the requirements of each application in a common format, thus allowing comparisons to be made and common requirements to be quantified.

Table 2-1. Surface Surveillance Radars (parameter table example)

	RF			IF	ADC		Digital Filter					Preprocessing						Output Interface			
	# Chan	RF Coverage (GHz)	RF BW (MHz)	IF BW (MHz)	Sample Rate (MHz)	BITS	Tunable	Output Bandwidth (MHz)	# Chan	Output Data Rate (MHz)	ENOB	Int & Dump	Az Presum	Fast AGC	Compress	PE	Custom	Interface Type	# Chan	Chan Width (Bits)	Chan Data Rate (Msps)
Radar1																					
Radar2																					

• • •

The following sections discuss the requirements compiled for each of the major mission areas described previously. Electronic warfare was broken out as a separate section because its receiver requirements are very similar across mission areas.

2.2 Surface Surveillance Radar

Surface surveillance radars can be subdivided into two categories, small and large aperture. These radars typically perform SAR and GMTI modes searching for stationary and mobile ground targets. The small radars are flown on numerous UAV platforms. These small surveillance radars generally make smaller maps at shorter ranges and thus can employ physically smaller Ku-band apertures. The large surface surveillance radars include long-range, airborne and space-based surveillance radars. The larger radars make larger maps at longer ranges and require X-band apertures to overcome the high atmospheric attenuation at Ku band. Additionally, the large surface surveillance radars are national strategic assets, which must have considerable ECCM capabilities to thwart enemy countermeasures. The ECCM requirement generally drives these larger radars to have a higher dynamic range than

the smaller radars to achieve the required level of jammer cancellation. The ECCM requirement also imposes a need for narrow band processing channels to perform space-time adaptive processing (STAP) for jammer nulling. In contrast, SAR and GMTI waveforms are generally wide band. The approach to meeting both of these seemingly conflicting requirements is to employ a digital channelizer (or filterbank) to provide wide band coverage and narrow band processing channels. For preprocessing, most of the smaller radars perform only those functions which are absolutely necessary, in order to reduce power consumption. Spaceborne applications take this to the extreme by performing nearly all preprocessing functions off-board, to conserve satellite battery power. However, it is still necessary to perform some custom preprocessing (e.g. digital beam-forming) on-board to reduce the data rate to levels acceptable by tactical data links.

2.3 Air Surveillance Radar

Air surveillance radars are tasked with detecting and tracking airborne targets at oftentimes long ranges. These radars can be airborne or ground-based. The long-range detection requirement forces these systems to operate at lower RF frequencies (UHF to S-band) with narrow detection bandwidths. The desire to detect small targets in the presence of ground clutter requires high dynamic range .

2.4 Strike, Combat and Counter Air

Strike, combat and counter-air radars are tasked with destroying targets with air-to-air missiles, homing antiradiation missiles (HARM), or varieties or guided and unguided bombs. Installation limitations on fighter aircraft, and to some extent cost, drive these systems to operate in the lowest possible RF (for maximum range performance) commensurate with the physical cavity provided for the radar aperture. Typically these are X-band or Ku-band radars. Platforms tasked with surface targeting will require SAR and GMTI modes which, in turn, require support for wide band waveforms. Air-to-air systems, and even those air-to-ground systems that require some form of air surveillance for survivability, require narrow detection bandwidths. Dynamic range tends to be moderate for surface targeting applications, and higher for air-to-air modes.

2.5 Electronic Warfare

In general, EW receivers present the most difficult requirements, demanding both very wide bandwidth and high dynamic range. Wide instantaneous bandwidths on the order of 1 GHz or more are needed to achieve a high probability of intercept on short-lived threat RF signals. Wide tuning ranges (typically 500 MHz to 18 GHz) are required to cover the RF range for threats of interest. Dynamic ranges of 60 dB or more (measured from minimum detectable pulse to saturation) require 11-12 bits. Because these requirements are difficult to meet at an affordable cost, compromises are often made. Tuning range can be reduced to cover the tactical fire control and anti-aircraft artillery radars in the 6-18 GHz band. Instantaneous bandwidth can be reduced from the gigahertz range to around 200 MHz, which is achievable with today's digital technology. ESM systems with these characteristics were included in our survey as medium-bandwidth (MB) applications. Finally, interferometer-based direction finding (DF) legacy systems were also considered and included in the survey.

Output data rates for nearly all EW applications are very low compared to radar because only a few digital pulse-descriptor words are output for each received pulse, as opposed to many I/Q samples during the pulse. The pulse descriptor words encode time-of-arrival, amplitude, frequency, phase, and pulse-width for each received pulse. Output data rates for ESM systems that perform specific emitter identification (SEI) can be much higher. SEI is a function that exploits the unique fingerprint each radar transmitter imposes on every transmitted pulse. It requires the output of I/Q data samples during the leading edge of the pulse, followed by FFT processing and template matching in the signal processor.

2.6 Communications

Tactical data communication systems are extremely diverse in RF center frequency, waveform type, data rates, and tactical employment. Nevertheless, several tactical communication systems are emerging as common standards to be applied across many applications. Out of the dozens of data links in military use, four candidates were chosen to provide the basis for receiver requirements: the tactical common data link (TCDL), common data link (CDL), joint tactical information distribution system (JTIDS), and global broadcast system (GBS). These systems are spread out across the whole RF band (from L to Ka band) and the data rates (and hence bandwidth) range from as little as 236 kbps to 274 Mbps – a

factor of 1000! The extremely high data rates will require receivers with very wide instantaneous IF bandwidths on the order of 450 MHz. However, these communication systems maintain backward compatibility with older and slower communications terminals that operate at the more moderate data rates of 10.71 to 45 MHz. These lower rates are more compatible with the bandwidths supported by MODRFS. Operation of CDL and TCDL require the ability to tune the receiver in 5 MHz steps. Operation of JTIDS requires rapid tuning (frequency hopping) across 51 channels of 3 MHz width, or implementation of a 51-channel filterbank.

2.7 MODRFS Requirements Summary

The preceding sections addressed the requirements for 23 different receiver applications. The goal was to develop general requirements for a large number of applications to bound the problem, determine the receiver performance drivers, and establish a basis for a common, modular receiver architecture — MODRFS.

Wide band EW applications and a few of the wide-band communication modes drive instantaneous receiver bandwidth requirements. Excluding those, however, most other applications require bandwidths consistent with the MODRFS goal. Dynamic range, on the other hand, is driven by the air surveillance applications. The challenge for MODRFS is to trade bandwidth for dynamic range to achieve high dynamic range over narrow bandwidths. Producing very narrow bandwidths from the wide-band A/D converter intended for the MODRFS receiver will require high-order digital filters and will drive the digital preprocessor complexity. Output data rates are driven by all SAR applications, which require the output of I/Q samples of wide-band waveforms. The data interface function of MODRFS will be application-specific to meet electrical back-plane requirements for established system designs.

Table 2-2 summarizes which applications drive the MODRFS requirements for each of its key parameters and whether the baseline MODRFS design (to be addressed in subsequent sections of this report) will comply with those requirements.

Table 2-2. MODRFS Requirements Drivers and Compliance.

Parameter	UAVs	GndSurv, Spa	GndSurv, Air	AirSurv, Gnd	AirSurv, Air	Strike	Air-to-Air	SEAD	SEAD ESM	WB ESM	MB ESM	NB ESM	WB Comms	MODRFS Compliance	Comments
Operating Frequency															
Channelizer	✓	✓	✓			✓	✓							Yes	
Extended Receiver		✓				✓	✓			✓	✓	✓		Yes	Now MODRFS baseline.
Higher Bands	✓							✓	✓	✓	✓		✓	Yes	Requires new RF front end
Lower Bands				✓	✓					✓	✓	✓		Yes	Requires new RF front end
Bandwidth															
Maximum										✓			✓	No	Requires improved ADC
Nominal	✓	✓	✓						✓		✓			Yes	
Minimum				✓	✓	✓	✓		✓					Yes	Limited by N-tap preprocessor FIR filter
Noise Floor															
Minimum BW				✓	✓		✓		✓					Yes	
Nominal BW	✓					✓		✓				✓		Yes	
Maximum BW		✓	✓						✓		✓			Yes	
Intermodulation[1]				✓	✓	✓	✓							Yes	
I/Q Image Rejection				✓	✓	✓	✓							Yes	
Matching															
Maximum BW	✓	✓	✓											Yes	
Minimum BW			✓	✓	✓									Yes	
Channel Isolation	✓	✓	✓	✓	✓		✓							Yes	

(1) 2 tones at -8dBSat
(2) Channel Pair Cancellation Ratio

The requirements shown in Table 2-2 indicate that the broadest possible application of MODRFS requires development of additional RF channelizers and down-converters. Instantaneous bandwidth and RF tuning ranges to support wide band ESM are not achievable in the baseline MODRFS design. MODRFS will support the maximum radar bandwidth and can collapse that bandwidth to a few megahertz with digital filtering after the A/D converter. The ultimate limit to the minimum bandwidth is set by the architecture of the digital filters. Digital filters with a broadband input and very narrow band output require a high order (i.e. large number of FIR filter taps), or more sequential stages of multirate filtering and decimation. Requirements for noise floor include the contributions from the A/D converter and receiver thermal noise. Intermodulation and I/Q image rejection requirements are driven by the need to detect small targets in the presence of large clutter returns. Channel-to-channel matching requirements are driven by multichannel SAR/GMTI and jammer cancellation applications.

3 Baseline MODRFS Architecture

MODRFS will realize the major elements of an RF receiver thread within a single line-replaceable module (LRM). MODRFS will comprise circuitry sufficient to accept a low-level RF input from an aperture and perform the functions of analog signal conditioning, digitization, and parameter encoding. MODRFS will have the ability to perform the receive function for a diversity of waveforms through reconfiguration of its internal digital preprocessor and adjustment of its analog circuitry. A typical system may employ a single or multiple MODRFS receivers. Section 3.1 describes the functions contained within MODRFS and highlights how multiple applications will be serviced by the common modular building objects (MBO's) comprising the receiver. Section 3.2 describes the MODRFS receiver interfaces. Subsequent sections describe the functionality and interfaces for each MBO.

3.1 Functional Block Diagram

MODRFS is realized by interconnecting the following set of modular building objects (MBO's), that can be tailored and reused across many applications.

RF Channelizer. Provides RF selectivity to pass a desired band of signals while rejecting others outside this passband. In some applications it may be a single bandpass filter, while a switched set of filters (or tunable filter) is required in other applications.

RF Down-Converter. Performs signal-conditioning operations on the RF signal, and down-converts the RF signal to an intermediate frequency (IF). In most applications, a variable-frequency local oscillator (LO) performs the receiver tuning operation within the RF down-converter. This MBO may include a RF gain control operation.

IF Down-Converter. Performs signal conditioning on the IF signal, and down-converts to the final signal that is to be sampled by the analog-to-digital converter (ADC). This MBO may include an IF gain control operation.

Analog-to-Digital Converter. Samples the received signal and outputs corresponding digital information.

Digital Preprocessor. Performs remaining receiver operations in the digital domain. These operations may include digital tuning and down-conversion, quadrature detection, filtering, equalization and other functions. The digital preprocessor also formats the digital data to correspond to the particular interface standard required by the application.

Module Control Unit. Facilitates control operations by interfacing with a common RF control/status bus. The module control unit (MCU) generates appropriate control interfaces needed by the MBO's. MCU operations must be performed without corrupting sensitive analog operations occurring in the receiver.

Figure 3-1 depicts how MODRFS is composed of inter-related MBO's and shows the external interfaces to be described in Section 3.2. Each of these MBO's is described in more detail in subsequent sections of this chapter.

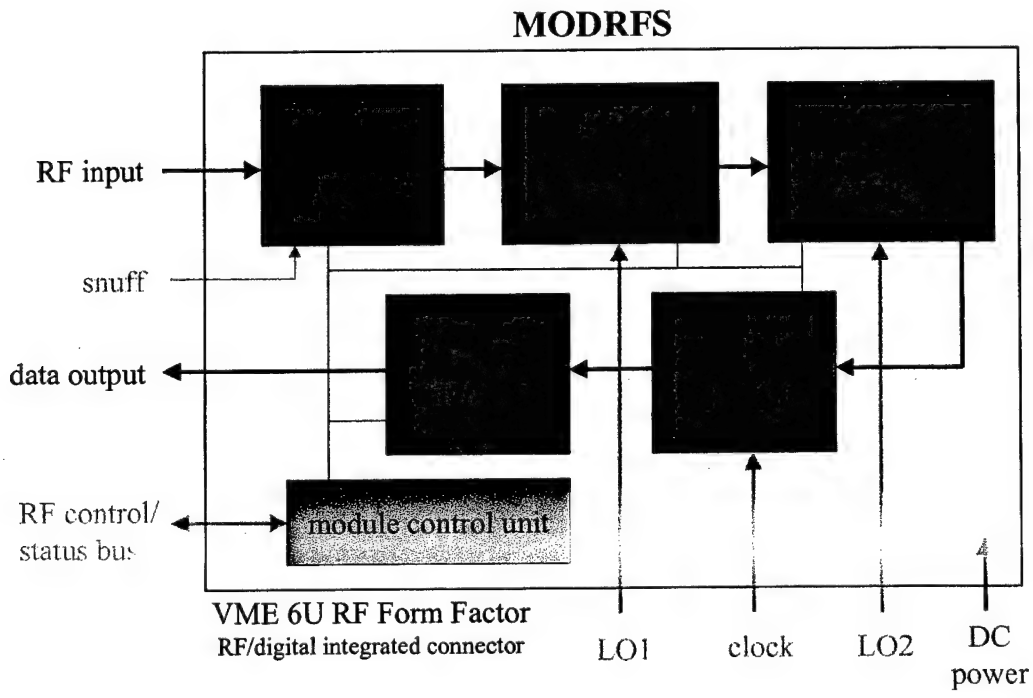

Figure 3-1 MODRFS interfaces and modular building blocks have been optimally configured to maximize use across many system applications

3.2 Interface Definition

External interface definition is key to realizing a family of MODRFS receivers that can be used across a variety of system applications. These interfaces are critical to design reuse and form the basis for an open system architecture (OSA).

A family of RF Channelizer and Down-Converter MBO's can tailor the RF input signal range to the particular application. Referring to Figure 3-1, receive operation will be facilitated by high-stability local oscillator (LO) interfaces. The first LO input, referred to as LO1, is an agile signal that can be varied in frequency to perform receiver tuning. In addition, LO1 can be a modulated signal for use in very wide signal bandwidth operations such as synthetic aperture radar (SAR). LO2 is a fixed frequency used to facilitate down-conversion to a range of frequencies suitable for digitization. A third stable signal is employed as a reference for generating the digitization-sampling clock.

The RF control/status bus facilitates receiver control. The realization of this bus has been optimized for RF module control applications. This bus has been documented in an Open System Architecture (OSA) specification as part of the Integrated Sensor System (ISS) OSA Program. The characteristics of this parallel bus have been optimized for control of RF modules to (1) minimize the number of interface lines to the module while delivering required level of service, (2) minimize the "overhead" impact to the module for realizing control services, and (3) provide minimum interference to module operations by allowing the bus to be silent during periods when signals are being received.

The snuff operation requires a discrete interface to maintain precision synchronization with the radar transmit waveform. The role of the snuff interface is to blank receiver operation during the transmit period so that it does not receive significant leakage from the transmit signal. This leakage can temporarily desensitize the receiver, preventing the proper processing of radar return signals. For most applications, this is the only required discrete interface to MODRFS.

MODRFS outputs digital data extracted from the received signal. The format of this output data depends on the selected data interfacing circuitry within the preprocessor MBO servicing a particular system application. In some applications this output data will be routed directly to a core processor, while in others it may be routed to another LRM for subsequent

digital preprocessing. In either case, the interface to the core processor may be electrical or optical.

MODRFS requires low-noise DC input power of sufficient stability to preserve system dynamic range. This, in turn, requires several stages of power conditioning to the prime power source to reduce its noise from several volts (typical) to sub-microvolt levels. MODRFS will be realized as a line replaceable module (LRM). This LRM will allow reliable electrical interconnection to the backplane, efficient thermal flow for cooling, and insertion/extraction into the rack enclosure. For the demonstration MODRFS receiver, a VME 6U-160 form factor was selected, shown in Figure 3-2. An OSA specification of this LRM form factor for application to RF/analog modules is being developed under the ISS OSA Program. MODRFS MBO's may also be applied to other form factors, including SEM-E.

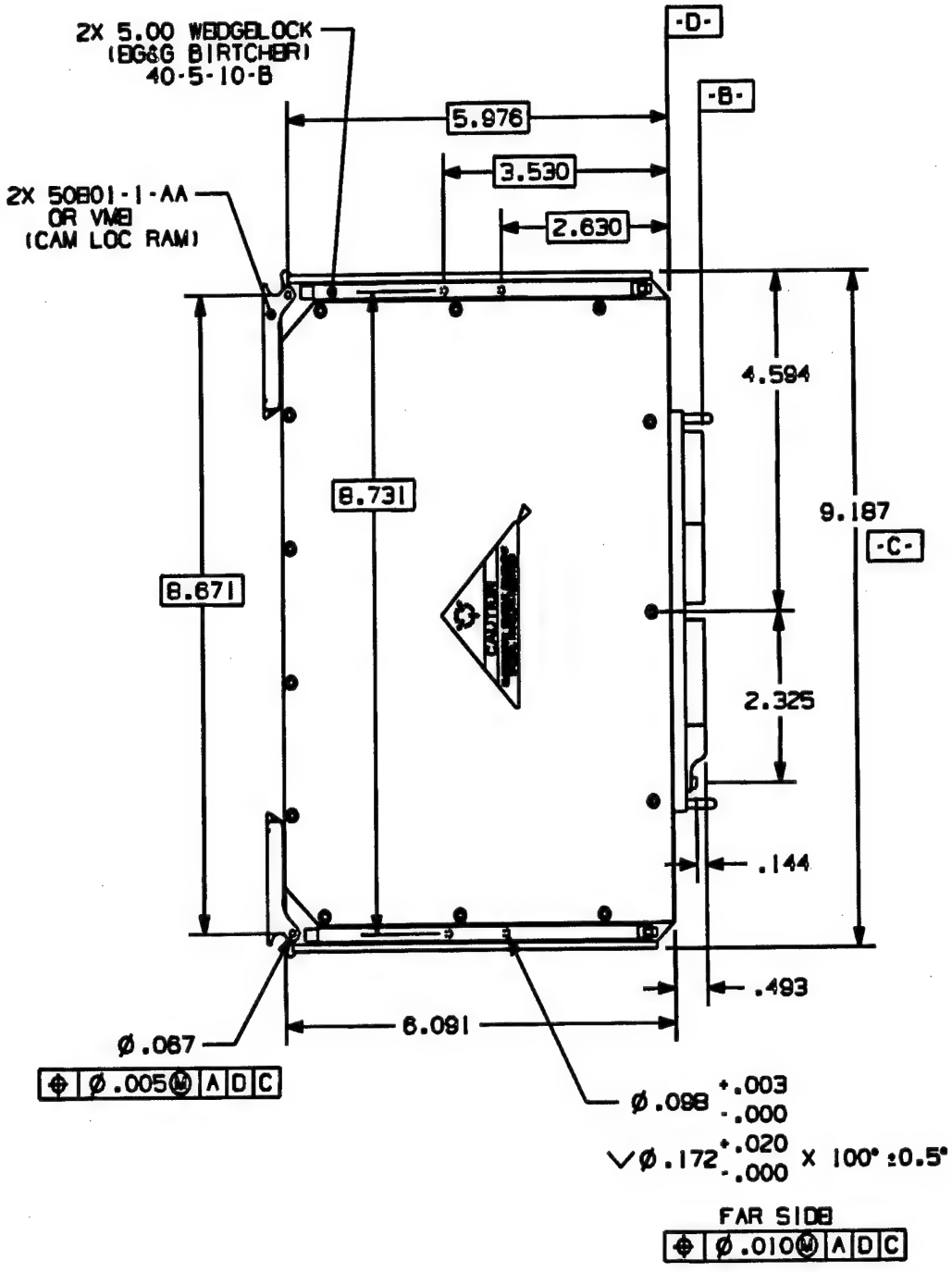

Figure 3-2 MODRFS will apply a standard VME 6U module definition developed by the ISS OSA program.

3.3 RF Channelizer Building Block

The MODRFS channelizer must provide the following functions:

- Image Rejection – The channelizer provides attenuation of unwanted signals that would otherwise fall into the image band and be down-converted by the mixer in the RF down-converter.
- Cross Modulation Suppression – The channelizer filters out-of-band jamming signals that enter the receiver front end and produce unwanted cross-modulation products.
- Calibration/BIT Test Input – The calibration port allows a switched path for an exciter signal to calibrate the receiver passband and perform BIT functions in the LPRF.
- Channel Selection – A switch will provide the ability to select one of four channels to filter the receiver input.

3.3.1 RF Channelizer Interfaces

The channelizer provides the RF connection between the radar antenna manifold and the RF down-converter in the receiver. It also includes a port for injection of a calibration signal from the exciter. Table 3-1 defines the electrical interfaces between the channelizer and the radar system.

Table 3-1 Channelizer Interfaces

Signal Type	I/O	Signal Description	Source or Destination
RF	Input	Receiver Input (Sum, Delta – Az, Delta –El, Guard, etc.)	From Antenna Manifold
RF	Output	Channelized Output	To RF Down-converter
RF	Input	Calibration/Built in Test	From Exciter
Control	Input	Calibration Port Select	From Module Control Unit (MCU)
Control	Input	Channelizer Band Select	From MCU
Control	Input	Channelizer Snuff	From MCU
Power	Input	+9 V, -8V DC	From LVPS

3.4 RF Down-Converter Building Block

The RF Down-converter must perform the following functions:

- Receiver Protection (R/P) – The R/P limits large signals that would destroy the sensitive analog components further down in the receiver cascade.

- Clutter Automatic Gain Control – AGC is used to attenuate large clutter signals, which would saturate the receiver at close range. The R/P driver provides fine attenuation control and linearization.
- Low-noise amplification – The low noise amplifier (LNA) provides low noise with enough gain to minimize the thermal noise contributions of subsequent stages in the receiver.
- Local oscillator (LO) amplification – The LO amplifier boosts the power of the exciter signal to the proper drive level on the LO1 mixer port.
- Frequency down-conversion – The mixer allows for either high- or low-side LO down-conversion and the LO signal is tuned to achieve the system operating bandwidth.
- Image Rejection (IR) – The IR mixer enhances the image rejection provided by the channelizer to ease the front-end filtering requirements.
- IF output switching – The down-converted signal can be switched to either of two outputs to provide the capability of separate IF filtered paths or to steer one of the outputs to an alternate receiver.
- DC Regulation – The input DC voltages are regulated and filtered to provide the proper voltages to the MMIC components in the down-converter.

3.4.1 RF Down-Converter Interfaces

The RF down-converter is placed between the channelizer and the IF down-converter in the receiver cascade. It also includes a port for injection of the LO1 signal from the exciter. The Table 3-2 below defines the electrical interfaces between the RF down-converter and the radar system.

Table 3-2 RF Down-Converter Interfaces

Signal Type	I/O	Signal Description	Source or Destination
RF	Input	Down-converter RF Input	From Channelizer
IF1a,b	Output	Down-converter IF Outputs	To IF Down-converter
LO1	Input	Local Oscillator	Exciter
SE TTL	Input	R/P Control Bus (12 bits)	From Common Bus
SE TTL	Input	LO1 Sideband Select	From Common Bus
SE TTL	Input	Control	From Common Bus
Power	Input	+9 VDC, -8VDC, AGND	From LVPS

3.5 IF Down-Converter Building Block

The IF down-converter must perform the following functions:

- IF signal amplification – Commercial (COTS) amplifiers will be used to the maximum extent possible to provide the signal gain necessary to raise it to the proper amplitude for A/D conversion. These parts are widely available in surface-mount packages from various vendors; however, because of the high dynamic range required in the MODRFS receiver, a thorough investigation will be performed to survey vendors for high-efficiency, high-intercept-point amplifiers.
- IF image rejection – This filter is required to prevent "IF away" noise from entering the mixer to minimize the added noise from the components that precede it.
- Noise automatic gain control – this attenuator is used in the system to control the noise level at the A/D to maximize sensitivity across multiple modes. Calibration as a function of frequency will be applied to linearize the attenuation.
- LO2 amplification and filtering – The LO signal from the exciter is boosted to the proper amplitude and filtered to prevent IF away noise from degrading the noise figure.
- Frequency down-conversion – The IF mixer operates with a high-side LO and down-converts to a second IF which can be sampled by the A/D converter.
- Equalization and nominal gain set – The equalizer will compensate for a slope in the gain characteristic and will be designed to provide a selectable slope. Several fixed-attenuator stages will be included to adjust the nominal gain setting in the receiver as well as providing improved VSWR at sensitive points in the receiver cascade.

- Anti-alias filtering – This filter will be centered at the second Nyquist interval for the MODRFS IF-sampled receiver. This filter attenuates the IF spectrum which would otherwise be replicated or 'aliased' into the base-band spectrum after A/D conversion and digital I/Q conversion.
- DC Regulation – The input DC voltages to the receiver will be converted to the proper working voltages to bias the IF MMIC components in the down-converter. Filtering will attenuate noise on the DC bias and will prevent the leakage of signals from other IF circuitry.

3.5.1 IF Down-Converter Interfaces

The IF down-converter connects the RF down-converter to the A/D converter building block in the receiver. The table below defines its electrical interfaces.

Table 3-3 IF Down-Converter Interfaces

Signal Type	I/O	Signal Description	Source or Destination
IF1	Input	Down-converter Input	From RF Down-converter
IF2	Output	Down-converter Output	To A/D converter
LO2	Input	Local Oscillator	From Exciter
Control	Input	NAGC Control Bus (5 bits)	From MCU
Control	Input	LO1 Sideband Select	From MCU
Control	Input	IF Output Control	From MCU
Power	Input	+9 V, -8V DC Power	From LVPS

3.6 A/D Converter Building Block

The A/D converter samples the IF down-converter second IF and outputs the digitized data to the preprocessor building block. A pipelined, feed-forward subranger is the clear architecture choice for the MODRFS performance range, as evidenced by its widespread use in the implementation of the fastest, high-resolution A/D converters currently available. The baseline architecture consists of a subranging front-end and an fine quantizer back-end

3.6.1 A/D Converter Interfaces

Table 3-4 below defines the electrical interfaces between the A/D converter and the radar system.

Table 3-4 A/D Converter Interfaces

Signal Type	I/O	Signal Description	Source or Destination
IF2	Input	Analog Input	From IF Down-converter
AD Clk	Input	A/D Clock	From Exciter
Data	Output	13-bit differential data bus	To Preprocessor
Data Ready	Output	Output data clock	To Preprocessor
Calibration Control	Input	TBD	From Module Control Unit
Overange	Output	A/D Full Scale indication	To Preprocessor
Power	Input	+9 V, -8V DC Power	From LVPS

3.7 Preprocessor Building Block

The preprocessor is responsible for providing data with the required bandwidth, data rate and dynamic range to the core processing algorithms, as well as for performing special high-speed computations that exceed the computational ability of the core processor. This section describes the top-level preprocessor functions.

All preprocessor functions can be implemented with combinations of seven different module types, as shown in Table 3-5. (The A/D converter is not part of the preprocessor module set, but is listed below to account for the different interface requirements).

Table 3-5 Preprocessor Module Types

Module Type	Variants	Implementation
A/D Converter	TRW, TCSF, ADI	Custom chips / MCMs
Tuner / Filter		ASIC
Format & Output	Application-specific	FPGA
AGC / PDW		FPGA
Bus Interface	Peripheral to VME Peripheral to Common Bus	FPGA
Channelizer	EW, Surveillance. Universal	ASIC
Azimuth Presum & FIFO		FPGA
Chirp-Compress		ASIC

Table 3-6 shows how the preprocessor module set will be used for various applications. Note that all applications require the peripheral-to-external bus interface, and nearly all require the Format & Output function. Those applications not requiring a Format/Output

function are those which will have other custom processing circuits on board. Note that nearly all applications desired the tuner/filter module.

Table 3-6 Preprocessor Module Applicability

Module Type	Radar1 SAR	Radar1 MTI	Radar2 SAR	Radar2 MTI	Radar3 SAR	Radar3 MTI	Radar4 SAR	Radar4 MTI	Radar5 SAR	Radar5 MTI	ESM1	ESM2	Surveill 1	Surveill 2	Air to Air	Comms
Tuner / Filter	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
-- NCO			✓				✓				✓				✓	✓
Format & Output	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	
AGC / PDW							✓	✓	✓	✓	✓	✓		✓	✓	
Bus Interface	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Channelizer											✓	✓	✓	✓		
Azimuth Presum & FIFO	✓				✓									✓		
Chirp Compress		✓		✓		✓		✓		✓				✓		
Other Custom													✓	✓		✓

3.7.1 Preprocessor Interfaces and Functional Requirements

Preliminary interfaces to the seven preprocessor modules are shown in Figure 3-7. These interfaces are intended to show the information required by, and output by, the module. The number of bits shown is preliminary and may change as the design evolves. Moreover, even though a circuit shows only a single pair of I/Q outputs, the implementation may require multiple outputs to accommodate the high data rates involved.

For simplicity, Figure 3-3, does not include interfaces such as clock distribution, control discretes, and propagation of the saturation bit from the A/D converter.

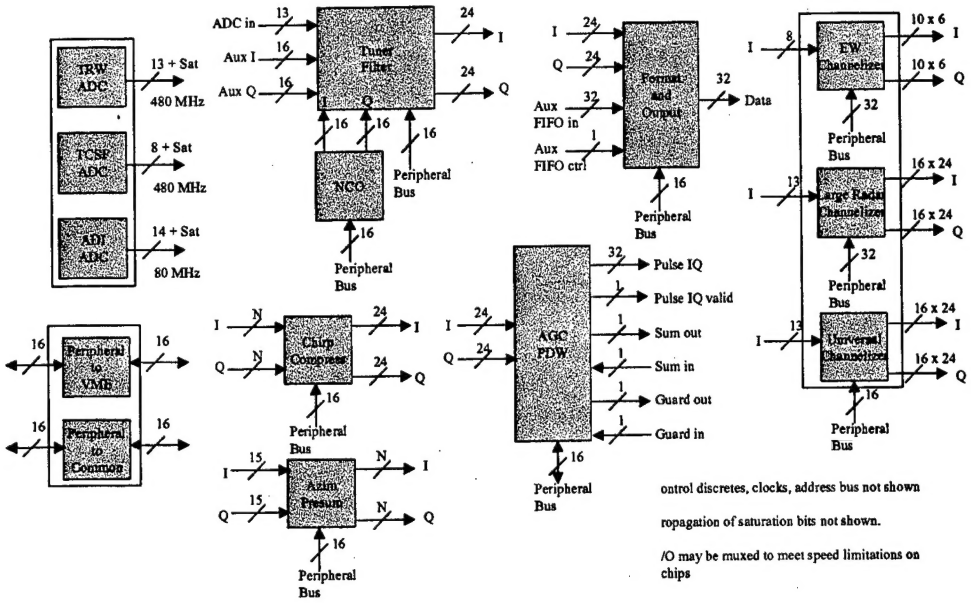

Figure 3-3 Preprocessor Module Interfaces.

3.8 *Module Control Unit (MCU) Building Block*

The MODRFS receiver will include a module control unit (MCU) that will interface to an external control bus and generate appropriate control interfaces to the integral building blocks. The external bus was developed and demonstrated by the Integrated Sensor System (ISS) Program, and has been further refined and published as an Open System Architecture (OSA) specification. A 16-bit multiplexed address and data bus, with separate strobes for address and data, provides the external control interface to the system. In addition to the external bus interface, the RF Down-Converter requires one discrete control signal from the Synchronizer for SNUFF function.

The Module Control Unit must perform the following functions:

- Receiver Control– The MCU receives setup data for each of the receiver building blocks over the 16-bit multiplexed address and data bus. Data transfers are initiated by programmable synchronizer strobes and occur during periods when the receiver is not active to eliminate crosstalk to the sensitive receiver electronics.
- Receiver Status – The bus is used to setup and register memory devices to allow reading back status for BIT/FIT purposes. Memory devices will be required to store

calibration data look-up tables for analog devices and sets of programmable coefficients for the digital preprocessing functions.

- Discrete Control – It is anticipated that several asynchronous control signals will be required in the MODRFS receiver where the latency of the control bus cannot be tolerated. For example the 'SNUFF' signal to the channelizer is a discrete control to shut off all RF paths to prevent a large RF spike signal from entering the receiver and saturating the IF and ADC building blocks.
- Level conversion – The current physical implementation of the bus uses differential ECL logic. Terminations are provided at both ends of the line in their characteristic impedance. ECL/TTL translators are used in the receivers to convert the ECL signals to single ended TTL levels for distribution to each of the MBOs.

3.8.1 Module Control Unit Interfaces

Table 3-7 below defines the electrical interfaces between the MCU and the rest of the radar system and the outputs from the MCU to the various building blocks in the MODRFS receiver.

Table 3-7 Module Control Unit Interfaces

Signal Type	I/O	Signal Description	Source or Destination
Control/Status Interface and Discrete Inputs			
AD_Bus	Input	16-bit bidirectional bus	From Controller
Addr_stb	Input	Address valid strobe	From Synchronizer
Data_stb	Input	Data valid strobe	From Synchronizer
Snuff	Input	Receiver Protector Discrete	From Synchronizer
Channelizer Output Controls			
Cal_sel	Output	Selects calibration input port	To Channelizer
Band_sel	Output	Selects channelizer band	To Channelizer
Snuff	Output	Shuts off all bands	To Channelizer
RF Down-converter Output Controls			
CAGC	Output	Controls clutter AGC	To RF Down-converter
LO1_sel	Output	Low/high side LO1 control	To RF Down-converter
IF_out_sel	Output	IF1/2 port output select	To RF Down-converter
Snuff	Output	Receiver Protector Discrete	To RF Down-converter
IF Down-converter Output Controls			
IF_BW_sel	Output	IF1 bandwidth control	To IF Down-converter
IF_In_sel	Output	IF main/aux input select	To IF Down-converter
NAGC	Output	Controls noise 6-bit AGC	To IF Down-converter
A/D Converter Output Controls			
A/D_Cal	Output	A/D calibration data	To A/D Converter
Preprocessor Controls			
Peripheral Bus	Output	TBD – see Section 3.7	To Preprocessor

4 Conclusion

MODRFS is an advanced digital receiver concept intended to satisfy a broad variety of system requirements. It is a technology base program that will demonstrate a modular, programmable receiver architecture that can be readily adapted to many radar, EW and communications applications.

In this report we described a methodology for collecting and categorizing system requirements which led to a set of digital receiver characteristics that would satisfy a large number of applications.

The various receiver components were partitioned into a set of modular building objects (MBO's); for each, we defined its function and identified its interfaces. The final objective is a universal receiver architecture for which a well-defined set of MBO's would allow their replacement and upgrading without altering the overall architecture and the performance of the other MBO's